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Comminution of solids due to kinetic energy of high-rate shearing: impact, shock, and shale fracturing

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ABSTRACT

Keynote: Fragmentation, crushing, and pulverization of solids, briefly called comminution, has long been a problem of interest for mining, tunneling, explosions, meteorite impact, missile impact and penetration, groundshock, defence against terrorist attack, and various kinds of industrial processes. Particularly intriguing is the idea that shock waves generated in the borehole by electrohydraulic pulsed arc could comminute gas shale so as to achieve a sufficient increase of permeability, which might allow reducing the discharge of contaminated water needed for hydraulic fracturing. Although many semi-empirical models for impact analysis abound in the literature, and whereas the fragmentation in the so-called "Mescall" zones of impacted or shocked solids has been explained by branching of dynamically propagating cracks, no viable comminution model appears to be available for macroscopic dynamic finite element analysis of large structures. The purpose of this article is to outline briefly the basic idea of such a model. In contrast to static fracture, in which the driving force is the release of strain energy, here the central idea is that the driving force of comminution under compression is the release of the local kinetic energy of shear strain rate, whose density can exceed the maximum possible strain energy density by several orders of magnitude. It is shown that the particle size or crack spacing should be proportional to the –2/3 power of the shear strain rate (a similar conclusion has been reached in 1983 by Dennis Grady for the fragmentation of a hollow metallic sphere due to high-rate volumetric strain caused by explosion in the hole). Further it is shown that the comminution by high-rate shear is mathematically equivalent to an apparent shear viscosity proportional to the –1/3 power of the shear strain rate and that the drop of the local kinetic energy of shearing is proportional to the 2/3 power of that rate. The proposed theory is shown to be analogous to turbulence. The local kinetic energy of shear strain rate is analogous to the kinetic energy of rotating eddies, separable from the kinetic energy of global motion, and the energy dissipation between forming particles is analogous to the viscous energy dissipation between adjacent eddies. A dimensionless characteristics analogous to the Reynolds number is formulated. The new theory greatly improves prediction of the exit velocity of missiles penetrating concrete walls.